

IMPACT OF CURING ON STRENGTH OF CONCRETE

SURESH B. PIPELWAR¹, NARENDRA M. KANHE² & DEVENDRA PANDEY³

¹Associate Professor & Head, Department of Applied Mechanics,

Manoharbhairam Institute of Engineering & Technology, Gondia, Maharashtra, India

²Principal, Gurunanak Education Society's Gurunanak Institute of Engineering & Management,

Dahegaon, Nagpur, Maharashtra, India

³Professor, Department of Civil Engineering, Manoharbhairam Institute of Engineering & Technology,

Gondia, Maharashtra, India

ABSTRACT

The present paper deals with the impact of insufficient curing on the strength of M15 concrete. The parameters of the study include the curing periods 3, 7, 9, 12, 15, 18, 21, 24 and 28 days for $<25^{\circ}\text{C}$, curing techniques adopted were air and captivation under water using Portland Pozzolona Cement. The specimen cubes were cast and cured under dissimilar conditions prior to testing. The study demonstrates that the method and duration of curing to a great extent affects the strength of concrete. Hence, excellent management of proper field curing is of the extreme significance. On the basis of interpretation of the results the following outcomes were made. Firstly, full time curing for 3 days and then air curing up to 15 days for $<25^{\circ}\text{C}$ gave desirable compressive strength of 15.90 N/mm^2 and was seemed adequate & justified. Secondly, 5, 7, 9 and 12 days full time curing with air curing up to 15 days for $<25^{\circ}\text{C}$ later was found to produce the concrete with sufficient strength, more than that desired for M15 concrete. Finally, full time water curing for 7 days is justified, as it gave the desirable compressive strength of 15.20 N/mm^2 of M15 concrete. In conclusion, the study makes a value addition in the parameters like conservation of water, reduction in project duration and expenditure on electricity/fuel, which in turn reduces the overall cost of the project in the regions where temperature is below 25°C .

KEYWORDS: Portland Pozzolona Cement (PPC), Full Time Curing (FTC), Concrete Mix (M15), Mean Strength (MS)

INTRODUCTION

The cement properties that are most significant in decisive curing requirements are strength gain, time of setting, and fineness. The time-span of mandatory curing of a concrete structure is sometimes directly linked to the strength-gain rate of the cementitious materials. The strength-gain time of cementitious materials can influence the strength gain of concrete, but other variables are also of concern most remarkably the water-cement ratio (U.S. Department of Transportation, 2005). The strength-gain rate of cement also affects the amount of cement essential in a concrete mixture to get a set strength in a required time gap. Curing plays a vital role on strength growth and stability of concrete. Curing takes place without delay after concrete insertion and involves preservation of preferred moisture and temperature circumstances both at depth and near the surface, for extensive periods of time. Accurately cured concrete has an ample amount of moisture for sustained hydration and growth of strength, volume stability, resistance to freezing and thawing, and abrasion and scaling resistance (www.cement.org). Concrete properties vary considerably depending upon the temperature and humidity that they have been subjected to early in their life (ACI, 1998). In order to obtain good concrete the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening

(Piplewar, et.al. 2013). Curing is the name given to procedure used for promoting the hydration of cement and consists of a control of temperature and the moisture movement from and into the concrete (IS: 456, 2000,). More specially the object of curing is to keep concrete saturated or as nearly saturated as possible, until the originally water-filled space in the fresh cement paste has been filled the desired extend by the products of hydration of cement (Shoba,et.al. 2005, Spears,1983). The necessity for curing arises from the fact that hydration of cement can take place only in water filled capillaries.

This is why a loss of water by evaporation from the capillaries must be prevented. Curing is the procedure of controlling the rate and amount of moisture thrashing from concrete during cement hydration. Concrete permitted to dry out without delay gain only 40% of the strength of the same concrete water cured for the full period of 180 days. Even three days water curing increases to 60%, at the same time as 28 days water curing increases it to 95% (Piplewar, et.al. 2013). Keeping concrete moist is therefore, a most effective way of increasing its ultimate strength (Arafah, et.al., 1996,). Due to improper curing the concrete may not gain its full strength and hair crack occurs on the concrete and the structure may fail (Rao, et.al. 2010, Bushlaibi and Alshamsi, 2002). Generally in practical life curing is done three or four times daily up to seven to ten days (Haque, 1990).

METHODOLOGY

The composition of the concretes in the present work was M15 concretes, prepared with Portland Pozzolona Cement. All the concrete cubes had the 100 mm slump. In the present study, series of tests were carried out as per IS: 516-1959 with these concrete cubes to determine; the crushing load and the effect of different modes of curing on the strength. Detailed results regarding the strength development of these concretes were analyzed. Concrete specimens were evaluated for $< 25^{\circ}\text{C}$. The water curing of the concrete included 3, 7, 9, 12, 15, 18, 21, 24 and 28 days of curing. Total 120 concrete cubes were analyzed in the present study as per IS: 9013-1978.

RESULTS & DISCUSSIONS

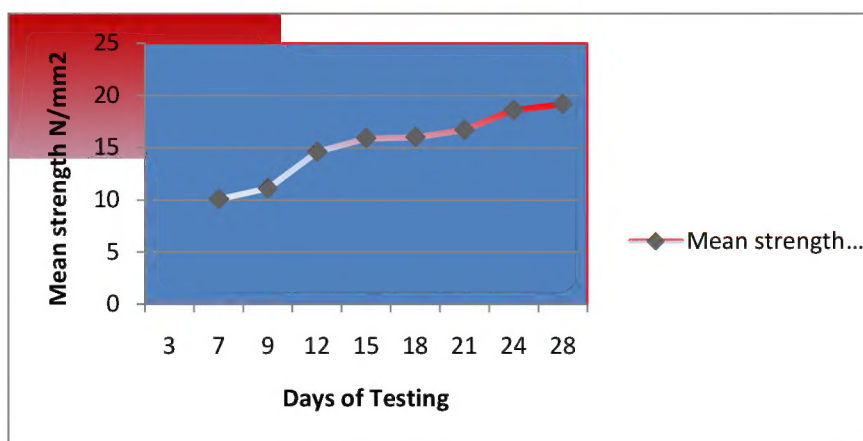
The effect of the different tenure of curing on the strength of the concretes is discussed in detail as under. The strength of the concretes with different tenure of curing is given in Table 1, 2, 3, 4 and 5. Whereas Table & Figure 6 illustrated full time continuous curing. The compressive strength that results through an age of 3,7,9,12,15,18,21,24 and 28 days for $<25^{\circ}\text{C}$ is illustrated in the Figure 1, 2, 3, 4 and 5 and the compressive strength as a percentage of the standard cured cube at the various test stages is summarized in the Table 1, 2, 3, 4 and 5.

The strength of the concrete cubes with full time water curing only for 3 days is given in Table 1. It is evident from the observations that the compressive strength gradually builds up with an age of 7, 9, 12, 15, 18, 21, 24, and 28 days full time continuous air curing for $<25^{\circ}\text{C}$ is illustrated in the Figure 1.

The results indicate that the strength of the concretes with full time water curing only for 3 days gradually increases with number of days. The maximum strength of 19.18 N/mm^2 is developed by the concrete mix-M15 in 28 days air curing, whereas after 15 days, the same concrete mix was found to gain 15.90 N/mm^2 . Full time water curing for 3 days at an age of 28 days of air curing increased the strength by 3.28 N/mm^2 in comparison to that at an age of 15 days air curing. The gain in mean strength reached to 3.18 N/mm^2 in comparison to that at an age of 18 days air curing. Whereas, the gain in mean strength reached to 2.48 N/mm^2 in comparison to that at an age of 21 days air cures and to 0.58 N/mm^2 in comparison to that at an age of 24 days air curing respectively. It seems that full time water curing only for 3 days is justified, as it gives the desired strength of M15 concrete after 15 days air curing.

Table 1: Showing Result of Full Time Water Curing Only for 3 Days

Mode of Curing	Days for Testing after Casting	Crushing Load on Cube in KN			Mean Crushing Load	Mean Strength N/mm ²
		1	2	3		
Full Time Curing of 3days	7	225	230	235	226.7	10.07
	9	255	220	280	251.6	11.10
	12	300	320	370	330.0	14.60
	15	355	360	360	358.3	15.90
	18	360	380	380	375.0	16.00
	21	355	390	385	376.6	16.70
	24	400	430	420	420.0	18.60
	28	420	430	445	431.6	19.18

**Figure 1: Shows Mean Strength of Full Time Curing of 3 Days**

The strength of the concrete cubes with full time water curing only for 5 days is given in Table 2. It is evident from the observations that the compressive strength gradually builds up with an age of 9, 12, 15, 18, 21, 24, and 28 days full time continuous air curing for $<25^{\circ}$ C is illustrated in the Figure 2. The results indicate that the strength of the concretes with full time water curing only for 5 days gradually increases with number of days. The maximum strength of 19.18 N/mm^2 is developed by the concrete mix-M15 in 28 days air curing, whereas after 15 days, the same concrete mix was found to gain 15.95 N/mm^2 . Full time water curing for 5 days at an age of 28 days of air curing increased the strength by 3.23 N/mm^2 in comparison to that at an age of 15 days air curing. The gain in mean strength reached to 3.18 N/mm^2 in comparison to that at an age of 18 days air curing. Whereas, the gain in mean strength reached to 2.81 N/mm^2 in comparison to that at an age of 21 days air cured and to 2.28 N/mm^2 in comparison to that at an age of 24 days air curing respectively. It seems that full time water curing for 5 days is justified, as it gives the desired strength of M15 concrete after 15 days air curing.

Table 2: Showing Result of Full Time Water Curing Only for 5 Days

Mode of curing	Days for testing after casting	Crushing Load on Cube in KN			Mean Crushing load	Mean Strength N/mm ²
		1	2	3		
Full time curing of 5days	9	250	265	285	266.7	11.85
	12	305	310	340	318.3	14.14
	15	356	360	361	359.0	15.95
	18	365	365	350	360.0	16.00
	21	360	370	375	368.3	16.37
	24	375	380	390	381.6	16.90
	28	420	430	445	431.6	19.18

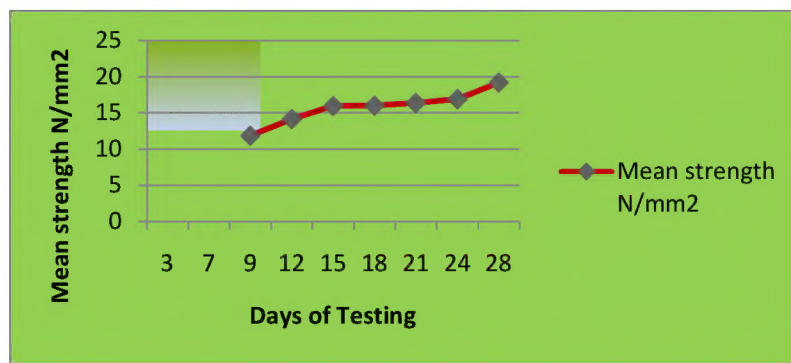


Figure 2: Shows Mean Strength of Full Time Curing of 5 Days

The strength of the concrete cubes with full time water curing only for 7 days is given in Table 3. It is evident from the observations that the compressive strength gradually builds up with an age of 12, 15, 18, 21, 24, and 28 days full time continuous air curing at $<25^{\circ}\text{C}$ is illustrated in the Figure 3. The results indicate that the strength of the concretes with full time water curing only for 7 days gradually increases with number of days. The maximum strength of 20.20 N/mm^2 is developed by the concrete mix-M15 in 28 days air curing, whereas after 15 days, the same concrete mix was found to gain 15.30 N/mm^2 . Full time water curing for 7 days at an age of 28 days of air curing increased the strength by 4.90 N/mm^2 in comparison to that at an age of 15 days air curing. The gain in mean strength reached to 4.10 N/mm^2 in comparison to that at an age of 18 days air curing. Whereas, the gain in mean strength reached to 3.50 N/mm^2 in comparison to that at an age of 21 days of air cured, and to 2.00 N/mm^2 in comparison to that at an age of 24 days air curing respectively. It seems that full time water curing for 7 days is justified, which yields the desired strength of M15 concrete after 15 days of air curing for $<25^{\circ}\text{C}$.

Table 3: Showing Result of Full Time Water Curing Only for 7 Days

Mode of Curing	Days for Testing after Casting	Crushing Load on Cube in KN			Mean Crushing Load	Mean Strength N/mm ²
		1	2	3		
Full Time Curing of 7 days	12	320	330	335	328.30	14.50
	15	330	350	355	345.00	15.30
	18	375	325	390	363.30	16.10
	21	355	390	385	376.60	16.70
	24	390	420	420	410.00	18.20
	28	455	460	450	456.60	20.20

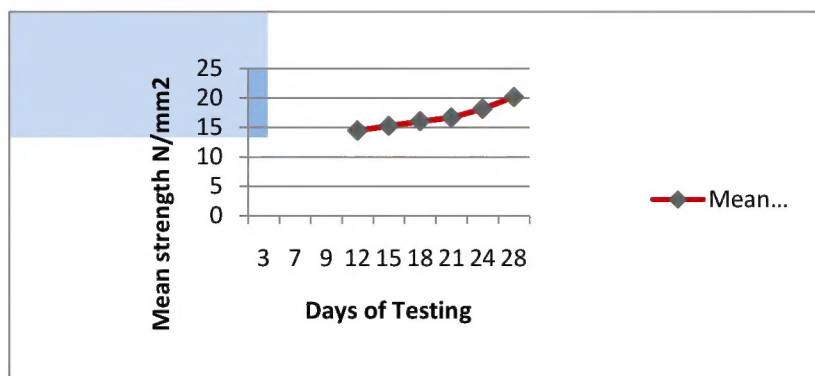


Figure 3: Shows Mean Strength of Full Time Curing of 7 Days

The strength of the concrete cubes with full time water curing only for 9 days is given in Table 4. It is evident from the observations that the compressive strength gradually builds up with an age of 15, 18, 21, 24, and 28 days full time continuous air curing for $<25^{\circ}\text{C}$ is illustrated in the Figure 4. The results indicate that the strength of the concretes with full time water curing only for 9 days marginally increases with number of days. The maximum strength of 20.80 N/mm^2 is developed by the concrete mix-M15 in 28 days air curing, whereas after 15 days, the same concrete mix was found to gain 15.16 N/mm^2 . Full time water curing for 9 days at an age of 28 days of air curing increased the strength by 5.64 N/mm^2 in comparison to that at an age of 15 days air curing. It seems that there is adequate increment in the strength. The gain in mean strength reached to 4.00 N/mm^2 in comparison to that at an age of 18 days air curing. Whereas, the gain in mean strength reached to 3.90 N/mm^2 in comparison to that at an age of 21 days of air cured, and to 2.00 N/mm^2 in comparison to that at an age of 24 days air curing respectively. It seems that full time water curing for 9 days is effectively justified, which yields the desired strength of M15 concrete after 15 days of air curing for $<25^{\circ}\text{C}$.

Table 4: Showing Result of Full Time Water Curing Only for 9 Days

Mode of Curing	Days for Testing after Casting	Crushing Load on Cube in KN			Mean Crushing Load	Mean Strength N/mm^2
		1	2	3		
Full Time Curing of 9 days	15	350	350	355	351.6	15.16
	18	375	380	380	378.3	16.80
	21	375	380	390	381.6	16.90
	24	390	440	440	423.3	18.80
	28	480	455	470	468.3	20.80

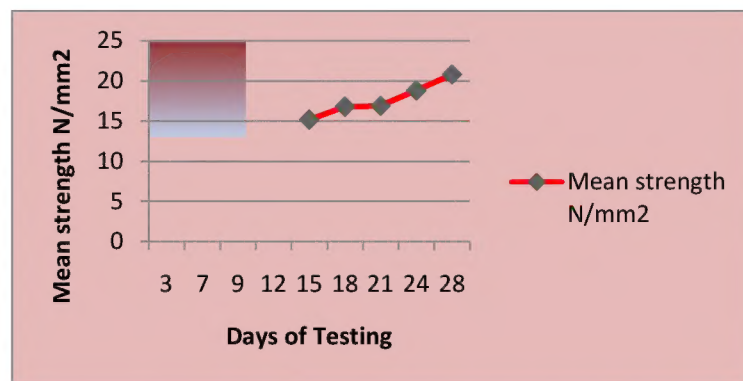


Figure 4: Shows Mean Strength of Full Time Curing of 9 Days

The strength of the concrete cubes with full time water curing only for 12 days is given in Table 5. It is evident from the observations that the compressive strength gradually builds up with an age of 15, 18, 21, 24, and 28 days full time continuous air curing for $<25^{\circ}\text{C}$ is illustrated in the Figure 5. The results indicate that the strength of the concretes with full time water curing only for 12 days marginally increases with number of days. The maximum strength of 21.18 N/mm^2 is developed by the concrete mix-M15 in 28 days air curing, whereas after 15 days, the same concrete mix was found to gain 15.78 N/mm^2 . Full time water curing for 12 days at an age of 28 days of air curing increased the strength by 5.40 N/mm^2 in comparison to that at an age of 15 days air curing. It seems that there is adequate increment in the strength. The gain in mean strength reached to 5.28 N/mm^2 in comparison to that at an age of 18 days air curing. Whereas, the gain in mean strength reached to 4.28 N/mm^2 in comparison to that at an age of 21 days of air cured, and to 2.00 N/mm^2 in

comparison to that at an age of 24 days air curing respectively. It seems that full time water curing for 12 days is seldom justified, which yields the desired strength of M15 concrete after 15 days of air curing for $<25^{\circ}\text{C}$.

Table 5: Showing Result of Full Time Water Curing Only for 12 Days

Mode of Curing	Days for Testing after Casting	Crushing Load on Cube in KN			Mean Crushing Load	Mean Strength N/mm^2
		1	2	3		
Full Time Curing of 12 days	15	357	355	353	355.0	15.78
	18	355	360	360	358.3	15.90
	21	375	380	390	380.6	16.90
	24	420	430	445	431.6	19.18
	28	470	485	475	476.0	21.18

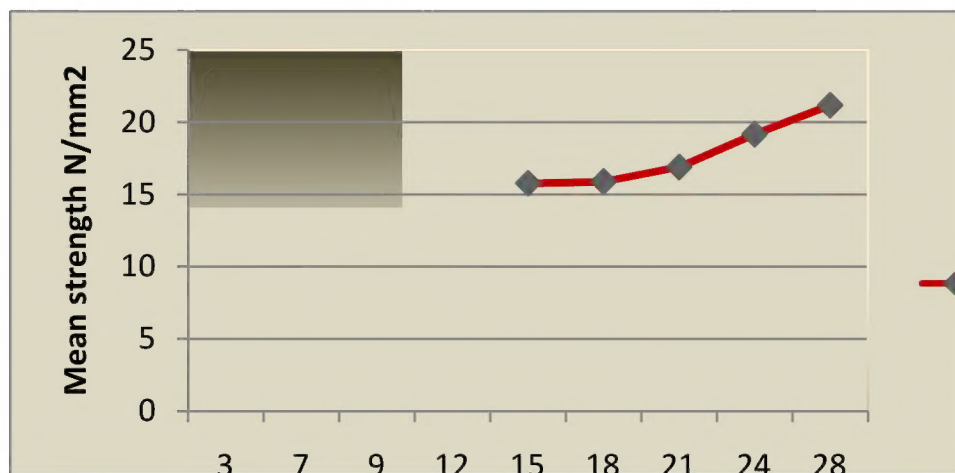


Figure 5: Shows Mean Strength of Full Time Curing of 12 Days

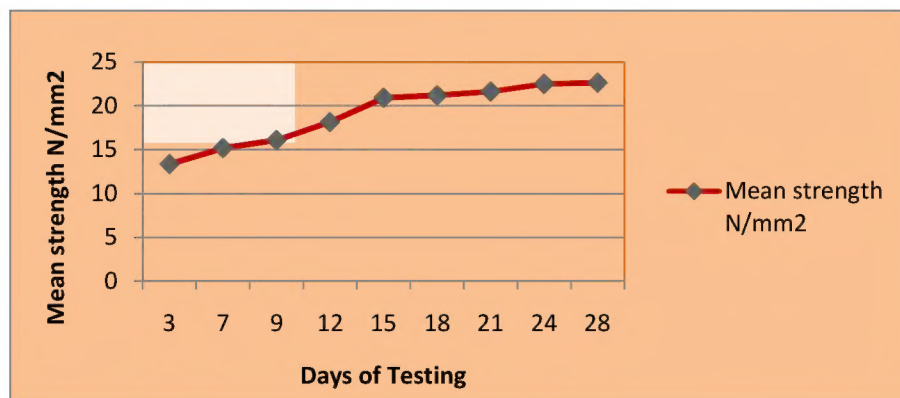
The strength of the concrete cubes with full time water curing for 3, 7, 9, 12, 15, 18, 21, 24 and 28 days is given in Table 6. The compressive strength results through an age of 3, 7, 9, 12, 15, 18, 21, 24 and 28 days full time continuous curing for $<25^{\circ}\text{C}$ is illustrated in the Figure 6. It is evident from the observations that the compressive strength gradually builds up with an age 3, 7, 9, 12, 15, 18, 21, 24 and 28 days,

The maximum strength developed by the concrete mix-M15 on 28 days is 22.67 N/mm^2 , whereas after 7 days same concrete mix gains 15.20 N/mm^2 . It seems that there is adequate increment in the strength to the desired level after 7 days. Full time water curing for an age of 28 days increased the strength by 7.47 N/mm^2 in comparison to that at an age of 7 days. The gain in mean strength reached to 6.57 N/mm^2 in comparison to that at an age of 9 days. The gain in mean strength reached to 4.50 N/mm^2 in comparison to that at an age of 12 days.

The gain in mean strength reached to 1.74 N/mm^2 in comparison to that at an age of 15 days. The gain in mean strength reached to 1.45 N/mm^2 in comparison to that at an age of 18 days. Whereas, the gain in mean strength reached to 1.02 N/mm^2 in comparison to that at an age of 21 days and to 0.14 N/mm^2 in comparison to that at an age of 24 days respectively. It seems that full time water curing only for 7 days is justified, as it gives the desired strength of M15 concrete.

Table 6: Showing Result of Full Time Continuous Curing

Mode of Curing	Days for Testing after Casting	Crushing Load on Cube in KN			Mean Crushing Load	Mean Strength N/mm ²
		1	2	3		
Full Time Continuous Curing	3	290	330	300	306.7	13.37
	7	340	342	344	342.0	15.20
	9	370	340	380	363.3	16.10
	12	480	490	470	416.7	18.17
	15	490	500	470	480.0	20.93
	18	490	500	470	486.7	21.22
	21	520	490	480	496.7	21.65
	24	500	520	530	516.7	22.53
	28	510	500	550	520.0	22.67

**Figure 6: Shows Mean Strength of Full Time Continuous Curing**

CONCLUSIONS

Curing is vital if concrete is to achieve the intended purpose over the design time of the structure, while too much of curing time may steer the increase of the structure cost of the project with needless delays. When there is insufficiency of water, curing with water is not easy particularly for cases where huge constructions have to be cured. Full time curing for 3 days and then air curing up to 15 days for $<25^{\circ}\text{C}$ was seemed adequate & justified as it gave desirable compressive strength of 15.90 N/mm^2 which is more than 15.00 N/mm^2 as an acceptable strength of any M15 concrete. 7 days, 9 days and 12 days full time curing and then with air curing up to 15 days for $<25^{\circ}\text{C}$ later on produces the concrete with sufficient strength, more than that desired for M15 concrete. The full time water curing for 7 days is justified, as it gave the desirable compressive strength of 15.20 N/mm^2 of M15 concrete. In conclusion, the study makes a value addition in the parameters like conservation of water, reduction in project duration and expenditure on electricity/fuel, which in turn reduces the overall cost of the project in the regions where temperature is below 25°C .

REFERENCES

1. ACI Committee 308, (1998), Standard Specification for Curing Concrete, ACI 308.1-98, American Concrete Institute, Farmington Hills, Michigan.
2. Arafah A., Al-Zaid R. and Al-Haddad M. (1996). "Influence of non-standard curing on the strength of concrete in arid areas", Cement and Concrete Research. 26(9): 1341-1350.

3. Bushlaibi A.H and Alshamsi A.M. (2002) "Efficiency of curing on partially exposed high- Strength concrete in hot climate" Cement and Concrete Research. 32(6): 949-953.
4. Curing of Portland Cement Concrete Pavements,(2005), Publication No. FHWA-RD-02-099, Volume II Final Report, U.S. Department of Transportation, (FHWA-HRT- 05-038), Virginia 22161.
5. Haque, MN. (1990) "Some concretes need 7 days initial curing". Concrete International, 12(2):42-46.
6. IS: 456-2000 Plain and Reinforced Concrete- Code of Practice. Bureau of Indian Standards, New Delhi.
7. IS: 516-1959 Methods of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi.
8. IS: 9013-1978 Methods of Making, Curing and Determining Compressive strength of Accelerated-Cured Concrete Test Specimens, Bureau of Indian Standards, New Delhi.
9. Piplewar,Suresh B., Kanhe,Narendra M. Pandey, Devendra. (2013) "Intermittent Curing of M15 Concrete", Int. J. Struct. & Civil Engg. Res.,ISSN 2319 – 6009,Vol. 2, No. 3,165-171.
10. Rao, M.V. Krishna, P. Rathish Kumar, Khan, Azhar M., (2010) "A study on the influence of curing on the strength of a standard grade concrete mix", Facta Universitatis Series: Architecture and Civil Engg. Vol. 8, No 1, 23-34.
11. Shoba M. and Raju P.S.N., (2005) "Effect of Curing Compound on different Concretes", New Building materials and construction world, vol-11, issue-4, October, 66-71.
12. Spears R E. (1983) "The 80 percent solution to inadequate curing problems", Concrete International, 15-18.
13. www.cement.org/for-concrete.../concrete.../concrete.../curing-in-construction.